RELIABILITY ASSESSMENT OF GSM POWER SYSTEM NETWORK

(CASE STUDY OF AIRTEL NIGERIA LIMITED)

BY

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DEPARTMENT OF ELECTRICAL ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

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MAY, 2011 DECLARATION

I declare that the work in the thesis entitled ‘Reliability assessment of GSM power system network (Case study of AIRTEL Nigeria Limited)’ has been performed by me in the Department of Electrical Engineering.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

……………………….	**………………………..**	**…………………….**
Sulaiman Kazeem	**Signature**	**Date**

CERTIFICATION

This thesis entitled ‘RELIABILITY ASSESSMENT OF GSM POWER SYSTEM NETWORK (CASE STUDY OF AIRTEL NIGERIA LIMITED) by Sulaiman Kazeem meets the regulations governing the award of the degree of Masters of Engineering (Electrical Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation**.**

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DEDICATION

In memory of my mum, Alhaja Rafat A. Sulaiman for her love and support. May Almighty Allah grant her paradise.

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My foremost gratitude goes to Almighty Allah for granting me the strength and vigor towards the successful completion of this programme. I sincerely appreciate the understanding and support of my wife, Ganiyat and my children, Lateefat, Abdulsalam, and Abdulsamad throughout the course of this study.

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Special gratitude goes to the entire staff of Airtel for carving time out of their tight schedule to share knowledge with me on most of the GSM reliability concepts applied on the Network.

ABSTRACT

This work presents the reliability assessment of the Power sub-system of the North West Region of Airtel network for a period of one year. The Power model was found to be an integrated setup of major Power subcomponents such as transformer, automatic voltage regulator, generators, rectifier system, battery bank, and Power control systems such as automatic transfer switch and automatic main failure, which are all interfaced in a definite topological structure, with unique redundancy model at each network site.The impact of critical power failure event at different hierarchical stations on the subscribers was also assessed. The reliability data for power sub-system was collected to determine the reliability indices of the power equipment. The data were analysed using the MATLAB version 7.4 software. The two-generator system at the integrated switch sites, integrated hub sites, terminal end sites and independent of PHCN power supply on the network exhibited relatively high reliability with fault tolerance by the prevalence of duty cycle availability indices of 51.83%, 56.00% and 56.5% respectively under a standard configuration of 50.00% duty cycle absolute availability index for a generator unit. The rectifier system with modules of failure rate of $0.040/10^3$h installed on the network was deduced to possess a high reliability index close to unity within a unit hour interval. Empirical findings show that the use of battery units with voltage rating of 3V, 6V and 12V on the network of -48V combinatorial battery bank system would yield relatively high reliability close to unity. The study result showed that the efficiency of the network power system model depends on the degree of automation of the subcomponents and the degree of ambient condition changes. It was concluded that the reliability standards of the GSM power sub-system are dynamic and depends on the redundancy mode of each subcomponents, the degree of redundancy, the failure ratings or lifecycle and scalability of the subcomponents unit used in the system under optimal working conditions of all the subsystems and ideal maintenance practice.

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LIST OF ABBREVIATIONS

AMF	Automatic Main Failure
AVR:	Automatic Voltage Regulator
BS:	Base Station
BTS:	Base Transceiver Station
BSC:	Base Station Controller
GSM:	Global System For Mobile Communications
MSC:	Mobile Switching Centre
MTBF:	Mean Time Between Failures
MTRN:	Mean Time To Repair Network
MTTF:	Mean Time To Failure
MTTR:	Mean Time To Restore
QoS:	Quality Of Service

DEFINITION OF TERMINOLOGIES

Automatic Voltage Regulator: A device that maintains the terminal voltage of a generator or other voltage source within required limits despite variations in input voltage or load. It is also known as voltage stabilizer.

Base Station Controller: the GSM equipment that handles allocation of radio channels, receives measurements from the mobile phones, and controls handovers from BTS to BTS (except in the case of an inter-BSC handover in which case control is in part the responsibility of the anchor MSC).

Base Transceiver Station: the GSM equipment that contains the subsystems for transmitting and receiving radio signals (transceivers), antennas, and subsystem for encrypting and decrypting communications with the base station controller (BSC).

Mobile Switching Centre: The Mobile Switching Centre is a normal ISDN-switch with extended functionality to handle mobile subscribers. The basic function of the MSC is to switch speech and data connections between BSCs, other MSCs, other GSM-networks and external non-mobile-networks. The MSC also handles a number of functions associated with mobile subscribers, among others registration, location updating and handover

Mean Time Between Failures: The average time a component works without failure. It is the hours of observation divided by the number of failures.

Mean Time To Repair: A measure of reliability of a piece of repairable equipment, giving the average time between repairs

Quality Of Service: A defined measure of performance in a data communications system. For example, to ensure that real-time voice and video are delivered without annoying blips, a traffic contract is negotiated between the customer and network provider that guarantee a minimum bandwidth along with the maximum delay in milliseconds that can be tolerated.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Since the advent of global system for mobile communication (GSM) in Nigeria in 2001, the telecommunication industry has been experiencing unprecedented expansion in the number of subscribers. However, this increase in the use of GSM network have put enormous pressure on the network operators to ensure reliability and quality of service desired by the customers, but the reality on ground is that many of the network operators have not achieved the desired results [1, 2].

Reliability and quality of service can be affected by either traffic congestion or network failure due to equipment malfunction. Many studies have been carried out to ascertain the performance of GSM operators in Nigeria based on the size of traffic carried by the network operator and the causes of congestion in the network [3]. However, much attention has not been devoted in the past to network failure due to power outages caused by equipment failures. These outages affect the reliability and quality of service rendered by the network operator. Hence, it is essential to determine the number of customers affected by these outages when such situations occur in order to establish the best methodology in the allocation of resources to minimise such occurrences.

1.2 THESIS OUTLINE

Chapter one presents the formulation of the problem, the aims of the study, and the motives that motivated the aims. The outline of the activities done to achieve the aims of the study was presented.

Chapter two presents the literature review and the structure of the hierarchical network under study. In this chapter, the major subcomponents of the network power system are outlined, and the features of each of the power subsystem are described. The operating power system model is presented, and the redundancy model of each of the major power subsystems is described with the presentation of their related reliability equations. The chapter concludes with the discussion of the characterization of the network power outages and the description of the events associated with critical power episodes when the network load is supported by only battery power.

Chapter three presents the methodology and strategies adopted for the sourcing and collection of reliability data. In this chapter, the primary reliability data collected for the major power subsystems are briefly described. The evaluation techniques used for the computation of secondary reliability data are presented and the data were analyzed using central tendency measure.

Chapter four presents the reliability results which were evaluated based on the redundancy model of each of the major power subcomponents on the power system model. Assessments of the reliability standards of each major power subsystem for the impacts of practices and considerations that causes variations of parameters under certain constant conditions are discussed. The impacts of critical episode events on network outage and customers are also discussed.

Chapter five presents the limitations observed during the course of the study. The summary of the findings discovered upon the assessments of the efficiency of the operating model; the operational conditions; and the reliability results, were highlighted. Conclusions on the deductions made on the reliability study were also stated. Recommendations on practices to enhance reliability standards on a GSM power system were outlined.

1.3 THESIS MOTIVATION

Wireless networks such as GSM network have become critical telecommunication infrastructure as million of people depend on these networks for daily communication. More so, many thousand more new customers are subscribing to wireless service every day. As networks grow, network operators face tremendous challenges not to compromise network dependability such as reliability, availability and maintainability [3, 4, 5].

However, this situation is complicated the more, since power supply from Power Holding Company of Nigeria (PHCN) is rarely reliable or available. Therefore, network operators are left with the option of generating power from alternative power sources and integrating them with other power subcomponents such as rectifiers, automatic voltage regulator and battery to ensure the reliability of GSM telecommunication network.

The operational reliability of the transmission and base station subsystem loads at each site is dependent on the efficiency and performance of the power system model at each site as well as the conditions of their operating environment. The stability of the power subsystem is technically required to eliminate failures in the form of current and voltage surges that could lead to equipment malfunction or failure due to device overheating and distortion which could impair network reliability.

Additionally, network outages due to power failures that affect different categories of sites such as the backbone Mobile Switching Center (MSC) sites, intermediate hub sites and terminal base transceiver stations could impact network performance, undermine network robustness and degrade the quality of service (QoS) offered by network operator. Hence, informed the need for the evaluation of a power system driven network reliability.

1.4 PROBLEM FORMULATION

The poor availability and dependability of public power amidst mobile network expansion compelled the exigency for a supplementary power infrastructure at GSM sites to support the operation of network transmission and base station equipment so as to guarantee network reliability and minimize the impact of network failures due to power outages on customers. The supplementary power infrastructure is an integrated system with a collection of different power subsystems, which include a transformer, an automatic voltage regulator, two identical generators, a rectifier system, a battery bank, an automatic transfer switch, and automatic main failure, all interfaced in a definite topological structure, with redundancy scale that tolerates faults, allows for operation handover, and permits some degree of equipment downtime before restoration to optimal efficiency. Not only is the assessment of the rated capacity and the reliability standard of the major subsystems important to ascertain their effectiveness, sufficiency or superfluity in the face of maintenance resource scarcity and allocation challenges, but also the examination of the efficiency of the entire power system model is imperative to minimize network vulnerability due to fault occurrence and power outage on operating subsystems on the model. The investigation of the operational ranges of the power subsystems and their survivability under dynamic nature of ambient and environmental conditions is critical to assess the reliability status of each subsystem on the model in the context of their survivability in the operating environment.

Meanwhile, the comprehensive assessment of this power system, in view of the diverse and hierarchical nature of GSM network site, poses several challenges. Therefore, strategic methodology needed to be developed to classify network sites in order of integration hierarchical levels as integrated switch sites, integrated backbone sites, integrated hub sites and terminal end site, all of which have power models of similar topological structure and functional subsystems, but with possible variable redundancy scale. Afterward, the model of the dominant operating power model on the network was formulated as shown in Fig 1.1.

The power infrastructure at KADMSS01 in Fig 1.1 below was adopted as the standard power model and the representative of the dominant operating power system model on all the network sites where the study was conducted. The power infrastructure shown below on Fig 1.1 consist of a transformer, an automatic voltage regulator(AVR), two identical generators, a rectifier system, a battery bank, an automatic transfer switch (ATS), and automatic main failure (AMF).The function of each of the above equipment is fully discussed in chapter two under literature review and theoretical background.

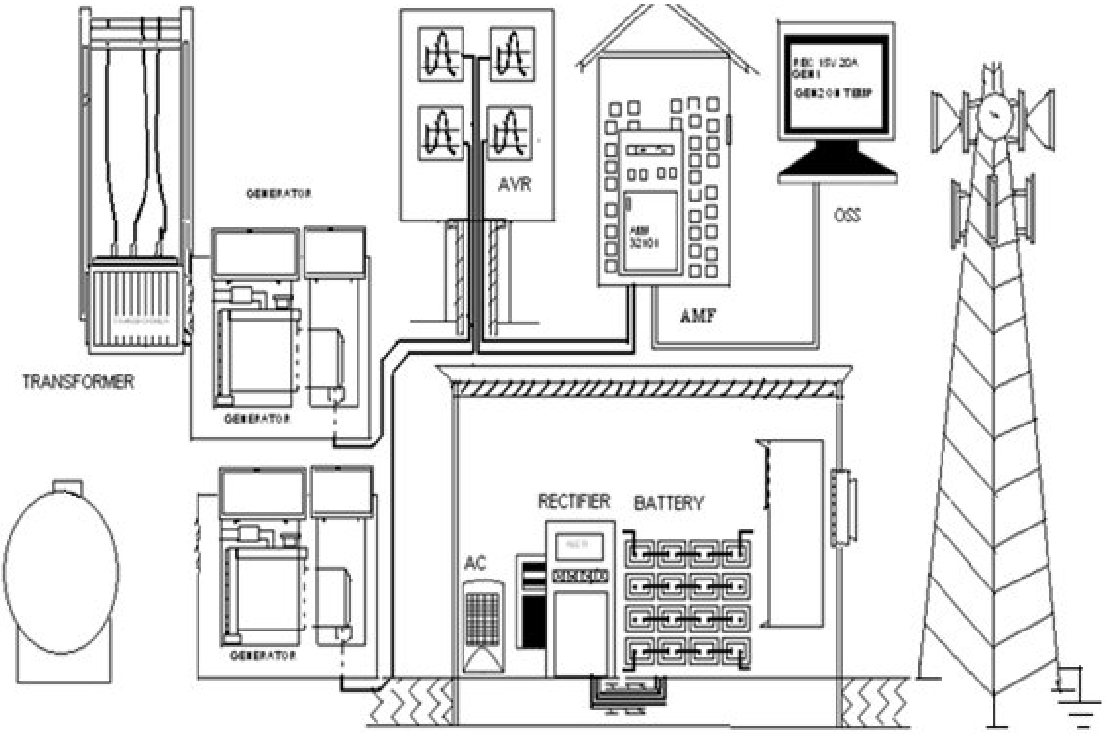

Fig 1.1: POWER INFRASTRUCTURE AT A GSM BASE STATION

KADMSS01 station is an integrated switch site supporting Mobile Switching Centre (MSC), Base Station Controller (BSC) and Base station Transceiver (BTS) loads on a common power system infrastructure that allows for flexible switching and automatic disconnection of low priority loads during critical power episode when the station loads are supported by limiting battery power. The power infrastructure at KADMSS01 station is an integrated power system consisting a transformer, an automatic voltage regulator(AVR), two identical generators, a rectifier system, a battery bank, an automatic transfer switch (ATS), and automatic main failure (AMF), all interfaced in a definite topological structure and installed in a unique environment to support optimal operation and sustain their survivability. The impact of the variation in redundancy scale for similar subsystems at different network sites was accounted for through the collection of reliability data samples from a number of different hierarchical sites so as to provide valid appraisal of the data with the aid of spatial data analytic tool. The examination of the nature and reliability features of each power subsystem at different network sites was done to identify similar features and develop strategy to account for the impact of variable features on the reliability standard of each power subsystem at different hierarchical sites. The assessment of the operational and ambient conditions of each subsystem was done to appraise the impact of these conditions on subsystem reliability standards. The effectiveness of the redundancy model of each of the power subsystem was verified by the evaluation and the appraisal of the reliability indices of each major subsystem computed based on the nature of its redundancy topology. The efficiency of the model was justified based on the appraisal of the reliability standards of each subsystem and the general performance of each subsystem under the influence of their operating and environmental conditions. The consideration of other potential factors that could flaw or enhance the redundancy model performance was also used as a metric to rationalize the efficiency of the model.

1.5 AIMS OF THE STUDY

The aims of the study include:

- To appraise the efficiency of the power system reliability model of the network and ascertain the degree of its vulnerability to power outages; its degree of tolerance to fault occurrence; and the impact of its vulnerability on network outage and customer satisfaction.

- To assess the reliability standard of each power subsystems based on their redundancy model and ascertain whether the reliability results justify the effectiveness of the redundancy model of each of the power subsystem.

1.6 MOTIVES FOR THE AIMS

The main motives that motivated this aims include**:**

- The prevalent challenge of erratic public power supply and the potential impact it poses on network vulnerability.
- The unprecedented expansion in network size amidst worsening state of public power and the potential effect of this phenomenon on the quality of service.
- The practical challenge of balancing the twin demand of efficient resource allocation, cost minimization and infrastructure reliability value maximization.
- The dynamic nature of ambient and environmental conditions and the shutdown impact of such ecological instability on equipment critical operational thresholds.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 INTRODUCTION

This chapter presents the literature review and the structure of the hierarchical network under study. The major subcomponents of the network power system and the features of each of the power subsystem were described. The operating power system model was presented, and the redundancy model of each of the major power subsystems was described with the presentation of their related reliability equations. The characterization of the nature of power outages was discussed. The description of the events associated with critical power episodes when the network load is supported by only battery power, was briefly explained.

2.2 LITERATURE REVIEW

Mas'ud [4] investigated fault management in intercellular network. This study showed that fault exists in the network due to radio frequency loss, down links and trunk outages. Intelligent agent technology was proffered as a solution to these problems coupled with preventive maintenance schedules. Chen [5], proposed empirical equations to the study of network reliability, availability, maintainability and survivability based on impacted episodes such as mean time to episode, mean time to restore network, quiescent availability, peak customer impacted and wireless prime lost line hours. These parameters provide understanding of network characteristics concurrent outages and also offer network operators valuable insights about predicting the frequency with which network episodes exceed severity thresholds. Snow *et al* [6] proposed wireless network infrastructure element. This includes base station, mobile switching centres, home location register and visitor location register database. The effect of mean time to failure and mean time to repair on the proposed network infrastructure was determined. These effects on network dependability were found to be significant impact. Albaghdadi and Razvi [7] studied 1320 cell GSM network. Their aim was to find an effective method for periodic transmission of network management information. The actual traffic loads were collected for 24 hours and analysed to determine their impact on the customer. Fawaz *et al* [8] investigated fibre optic cable system reliability. It was concluded that the frequency of failure of optical network is not negligible and that cable cuts are the dominant failure scenario for long optical fibre networks. In analysis of network reliability based on power outages, Goel and Gupta [9] proposed a window based simulation tool for reliability evaluation of electricity generating capacity using the Monte Carlo simulation. This simulation technique compared favourably with the analytic solution obtained from Markov analysis in the prediction of the loss of load expectation and the loss of energy expectation. Also, the developed Monte Carlo simulation can provide information regarding the unit forced outage rates, variations in system peak load and the cause consequences of partial generator unavailability. Paska [10] proposed novel approaches, models and tools to the electric power system reliability assessment on the first two hierarchical levels, with special attention to generating reliability assessment and computer program for generating adequate evaluation. Silverstein and Porter [11] described a methodology of contingency ranking for bulk system reliability criteria. This deterministic approach provides planning criteria for contingencies planning such that minimum acceptable performance level can be achieved. Outage data and models for multiple outages to examine the likelihood of various contingencies were provided. Burgis et al [12] investigated the reliability evaluation of a combined power system consisting of photovoltaic and wind power generation coupled with an uninterruptible power system using Monte Carlo simulation method. One important finding is the estimation of the critical loads interruption over a certain period of time. Chowdhury et al [13] provide performance reporting of an area power pool using probabilistic technique. Mid-continent area power pool experiences outages that can be classified as either planned or forced outages. The impacts of such outages on the area pool were provided, showing significant impact on the delivery of power to the area power pool. Billinton [14] provided an insight to Canadian experience in the collection of transmission and distribution component unavailability data. This information contains the classification of various outages of the equipment, the causes and effects on both the utilities and the customers impacted. Also, from the data presented further analysis can be undertaken such as forced outage rate, utilisation forced outage probability and incapability factor.

2.3 STRUCTURE OF THE NETWORK

The Global System Mobile communication (GSM) network is a typical hierarchical network in which the nodes in the network have different level of priority such that some low class nodes homes on higher priority nodes for initiation or termination of calls through hierarchical handover [3]. Each node is a network site with different level of integration of hierarchical transmission stations with different load demand, load distribution and traffic capacity as presented in Table 2.1. Site hierarchy priority is a function of the number of customers that would be impacted when total network outage occurs at the site.

Table 2.1: Load emand and Load Distribution at Hierarchical Integrated Network Station

Hierarchical Site	**Traffic Types**	**Traffic Capacity**	**Transmission Station**	**Load Demand (kVA)**
Integrated switch site	Inter MSC,BSC and BTS traffics	Platinum ≥1000Earlangs	MSC, BSC and BTS stations	300
Integrated backbone site	Inter MSC,BSC and BTS traffics	Gold 500≤Erl<1000	BSC,≤15BTS stations	30
Integrated hub site	Inter BTS and BTS traffics	Silver 100≤Erl≤500	≤10 BTS stations	20
Terminal end site	BTS traffics	Bronze≤100Erl	Single BTS station	13

Source: Survey on the North West Region of Airtel Nigeria Limited, January 2009

Each network site comprises of power system equipment and transmission system equipment which are connected and interfaced in specific configurations in accordance to the reliability requirement at the hierarchical site [4]. Each integrated site consists of network transmission loads run on a common power system and integrated on a power busbar that give room for load prioritization, flexibility of automatic switching and load disconnection during critical power episodes.

The hierarchy of network station observed on the North West section of Airtel telecommunication network was presented in Table 2.1. Some of the specimen sites where the research study has been conducted are shown in Table 2.2. The sites are classified as integrated switch site, integrated hub sites and terminal end sites.

Table 2.2: Some hierarchical stations on the North West Section of Airtel Telecommunication Network

Site	**No. of MSC**	**No of collocated BSC**	**No. of dependent hub site**	**No. of dependent end site**
KADMSC01	1	1	20	102
KADMSC02	1	1	22	114
KANMSC01	1	2	25	112
KADMSS01	1	1	10	100
ABMSC01	1	2	30	118
KADBSC021	1	1	11	40

KADBSC09	1	1	11	60
Site	**No. of MSC**	**No of collocated BSC**	**No. of dependent hub site**	**No. of dependent end site**
ZARBSC14	-	1	12	59
KANBSC22	1	1	15	80
KANBSC09	1	1	11	74
KD0049	_	-	_	1
KD0030	_	-	_	1
KD0047	_	-	_	1
KD0041	_	-	_	1
KD0037	_	-	_	1
KD0050	_	-	_	1
KD0063	_	-	_	1
KD0064	_	-	_	1
KD0101	_	-	_	1

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January 2009

The integrated switch sites are those stations installed with power resource that simultaneously energize MSC load, BSC load and BTS load on diverse busbars as exemplified by KADMSC01 network site in Table 2.2. Integrated hub sites are those network stations installed with power resource to concurrently energize a hub BSC facilities and terminal BTS equipment. ZARBSC14 network site is an example of station in this category. The Terminal end sites are network stations installed with power resource to support a single BTS coverage loads as exemplified by KD0049 network site.

2.4 MAJOR SUBCOMPONENTS OF THE NETWORK POWER SYSTEM

Basically, the typical GSM site comprises the following power subsystems, viz:

- Generator unit
- Automatic Transfer Switch(ATS)
- Automatic Main Failure(AMF)
- Stabilizer
- Rectifier
- Battery bank

2.4.1 Generator Subsystem

The generators are water-cooled, four-cylinder head, high-speed, electronic injector generator which generates alternating voltage during public power outage. The operation of the generator is automated so that the system tolerates fault as its operational and ambient conditions transcend critical limits. The generator is structured with automatic oil-gauge, fuel-gauge, voltage-level, temperature-level, running speed monitoring sensors and status register that stores operation events for ease of fault management. Each generator unit is fed from a calibrated rectangular or cylindrical painted metallic tank mounted on rigid supports few centimeters above the horizontal floor with a full capacity of 5000 litres and installed with a fuel level metering scale and level-monitoring sensors which triggered automatic generator shutdown and alert alarm signal to the Network Monitoring Centre (NMC) when critical fuel limit is attained.The monitoring system consists of relay sensors which are embedded in the Automatic Monitoring Failure (AMF) panel. These sensors transmit alert signal to the centralized Network Monitoring Controller over the network when abnormal condition pop up within the power unit. The alarm status register enhances flexible diagnostic test, simplifies fault localization, detection and correction. Therefore, it eases the maintainability of the machine. The generators are enclosed within painted sound proof metallic casing that keep equipment within moderate ambient condition. This device is mounted on an elastic vibration system and properly earthed to ground to provide adequate protection against voltage and current surges due to thunderstorm or lightning. The onsite generator rated output power is often above the load demand so as provide flexibility for base station load upgrade due to network capacity expansion.

2.4.2 Rectifier Subsystem

Rectifier system is an indoor network power equipment with partial active redundancy system of non-repairable independent rectifier module, and maintained within low ambient temperatures. The scale of redundancy of the modules for particular rectifier system varies for hierarchical station and specified by the Firm's standards that are driven by economics. The number of least functional active module required for the operation of the system depends on the installed transmission load capacity at the network site and it is configurable. The number of active module redundancies on a rectifier system at a site varies with the rate of module failure event and the mean time of module replacement. Rectifier system failure occurs when the number of failed modules increased to an instance whereby the number of active functional modules reduced below the threshold critical value such that there is no redundancy. Module failure event below threshold functional active module results in rectifier system downtimes that caused critical power episodes. The threshold number of functional active module is configured for hierarchical network station. Rectifier module failure may be caused by sudden ambient high temperature, module lifetime expiry, and abrupt overvoltage event and so on. Rectifier systems are secured by protective circuit breaker which normally activates system High Voltage shutdown and rectifier downtime during instances of overvoltage and over current.

2.4.3 Automatic Voltage Regulator (AVR) Subsystem

The AVR is indoor or exterior network power equipment that stabilizes or actuates the input AC power parameters (frequency, voltage, phase) supplied from the transformer. The equipment is a Surge Protection device which active uptime is configured and automatically turns on only when the Public power voltage supply appears across the transformer.

It is interfaced to the transformer to deliver the supplied Public power parameters at standards safe for the operation of the transmission loads. The AVR consists of phasor module, frequency regulator and voltage regulator modules and adaptive transformer that setup the AVR for input voltage within configured input ranges. Most AVR are embedded with temperature sensors and secured with circuit breakers that permit the equipment shutdown and outage at critical temperature and input overvoltage states. The phasor, frequency regulator and voltage regulator modules are complex and designed to have high reliability and performance with electronic component redundancies. The operational and power specifications and standards observed for hierarchical network stations are presented in Appendix 1.

2.4.4 Battery Bank

This is an indoor arrangement of identical batteries that provides standby power in events of the complete failure on the AC supply unit. It consists of an array of rechargeable lead accumulator or nickel-cadmium batteries that are maintained within moderate ambient temperatures in the proximity of the battery temperature ratings and dry airy condition. The battery bank is a -48V combinatorial system configured to support and sustain network transmission load for configured interval of time, beyond which automatic load disconnection occurs at battery low voltage states, resulting in potential network outage when AC system failures restoration is delayed. The batteries are connected in series-standby configuration to minimize their draining rate and enhance the availability and the dependability of the battery bank during critical power episodes. The battery bank is connected to a boost charging system during the AC unit uptime. Battery bank shutdown is induced by abrupt ambient high temperature states. The battery standards and specifications observed for hierarchical network station are presented in Appendix 1.5

2.5 THE NETWORK POWER SYSTEM MODEL

The dominant operating Power System Reliability model in the section of the network under study is presented in Fig 2.1. The model is formulated on the assumption of ideal switching devices and ideal DC transmission load. The generator units are assumed to be identical, independent and of the same constant failure rate. The rectifier modules are also assumed to be identical, independent and of the same constant failure rate. The same assumption holds for the battery units that make up the battery bank.

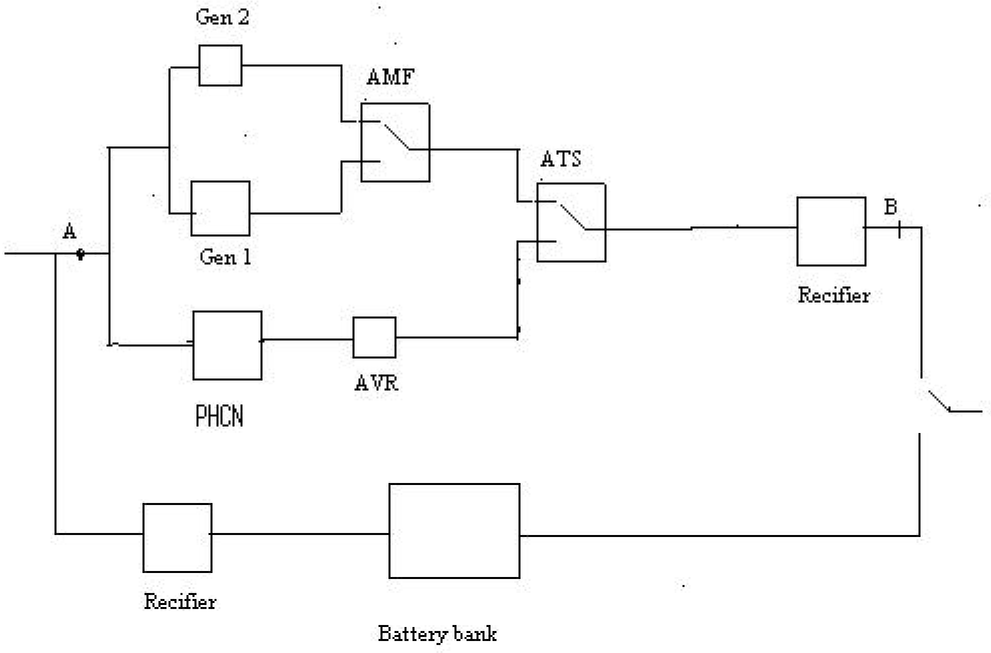

Fig 2.1: The Dominant Network Power System Reliability Model

The power model consists of two identical generator units connected in a standby configuration such that the generator-set operation are changed over for a configured interval of time (often every 12 hours) with the aid of the Automatic Main Failure (AMF) unit which is composed of plastic case electromechanical relay switches. The output of the AMF is interfaced with the Automatic Transfer Switch (ATS) unit, which is a control switching relay that deactivates the operation of the generator set and gives upper priority to public power feeding only on availability condition such that the combined generator set forms a standby topology with the public power AC supply. The conventional public power equipment is cascaded with an Automatic Voltage Regulator (AVR) which stabilizes the supplied output AC voltage, frequency and phase and passes them within equipment utility level.

The regulated AC voltage from the stabilizer is fed into a logic controlled electronic Rectifier embedded with flexible regulation system. The rectifier consists of a specific number of identical modules that are connected in parallel to the DC power output busbar such that the DC load is supplied from the rectifier only if at least a certain number of the modules are active while the battery bank is being charged through a DC-DC converter. Therefore, the failure of a certain number of the rectifier modules automatically commutates the power supply to the DC load from the standby battery bank.

2.6 REDUNDANCY TOPOLOGY OF POWER SUBSYSTEM ON THE MODEL

In this section, the redundancy topology of each of the major power subsystem is briefly described.

2.6.1 Redundancy Topology of Generator

The generator system on the GSM Power Reliability model is a two-identical generator standby redundancy system which is a model of an n-identical generator standby redundancy system with n-1 redundancies. The reliability is given by [10].

$$= \qquad 1 + \qquad + \frac{}{!} + \cdots \frac{}{(\quad)!} \tag{2.1}$$

with a added weight value $= \frac{}{(\quad)!}$ (2.2)

which predicts the inherent behavior of the reliability with sequential increase in the number of generator unit ,n, on the system.

n is an integer representing the number of generator units in the system, and is the failure rate, such that ≥ 2

In a power reliability system, the choice of the value of n is dependent on the maintainability, repair rate, the presence of alternative power supply redundancy and cost considerations. The value of the instantaneous failure rate is dependent on the lifecycle of the generator, the frequency of repair and the rate of part replacement.

2.6.2 Redundancy Topology of Rectifier System

The rectifier system on the GSM Power Reliability Model is a partial active redundancy system with an n-identical rectifier module and r-least number of active modules for the functional operation of the system. The scale of redundancy of the rectifier modules and the minimum number of active module for the functional operation of the rectifier system vary for hierarchical stations. The distribution of the rectifier module for hierarchical site at optimum efficiency is presented in Table2.3.

Table 2.3: Rectifier Modules for hierarchical network site

Hierarchical site	No. of modules per rectifier stand	Least number of active modules
Integrated switch site	24	16
Integrated backbone site	16	8
Integrated Hub site	8	4
Terminal End site	8	2

Source: Statistical Survey on the North West Region of Airtel Nigeria Limited, January, 2009

The reliability index of the partial active redundancy rectifier system with n rectifier modules and configured with r minimum rectifier modules at optimal operating temperature and conditions is expressed as [10]

$$R = \sum ( )(1 - R) R \tag{2.3}$$

This can be expanded as:

$$R = ( )(1 - R) R + ( )(1 - R) R + ( )(1 - R) R + \cdots ( )(1 - R) R \tag{2.4}$$

Where the Reliability is index of a unit module and is expressed as

$$= \tag{2.5}$$

is the least number of active for the functional operation of the rectifier system and is a unit Rectifier module failure rate and t is the observed time interval.

2.6.3 Redundancy Topology of Battery Bank System

The battery bank is an n-identical standby string of m-series connected batteries. The m-series connected battery is a -48V combinatorial system. The topology of the redundancy mode of the battery bank is shown in Fig 2.2.

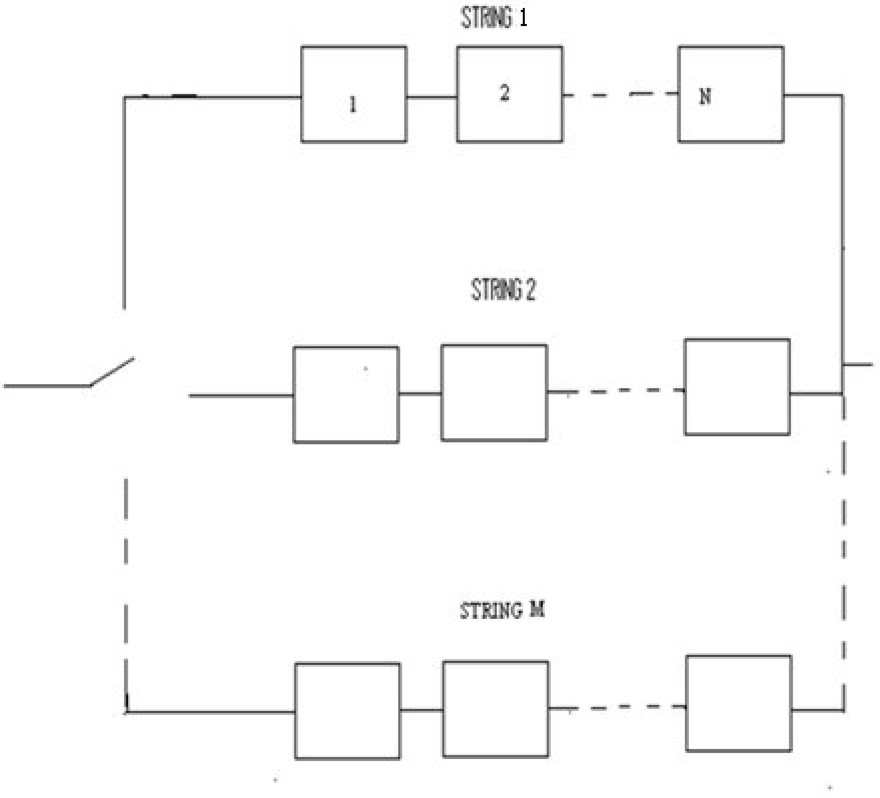

Fig 2.2: Reliability Model of the Battery Bank at a Network Site

The number of standby string redundancies and series unit battery per string for the battery bank system vary for hierarchical network site and the distribution for the network under study is presented in Table 2.4.

Table 2.4: Distribution of backup Battery for hierarchical network Site

Hierarchical site	**No. of String Row**	**No. of Series Battery Per String**	**Unit Battery Voltage Rating (V)**	**Sustenance Time (hr)**
Integrated switch station	16	4	12	24
Integrated backbone site	8	4	12	12
Integrated hub site	4	4	12	10
Terminal end site	2	4	12	8

Source: Statistical Survey on North West Region of Airtel Nigeria Limited, January, 2009

The reliability index of the battery bank with n strings and m-series battery per string at constant temperature and operating condition is given by [10].

$$R = e \qquad 1 + m\beta t + \frac{(\quad)}{!} + \cdots \frac{(\quad)}{(\qquad)!\text{`}} \tag{2.6}$$

With an added weight

$$w \quad = \frac{(\quad)}{(\qquad)!\text{`}} \tag{2.7}$$

This weight predicts the behavior of the reliability with incremental change in the number of strings of the battery system.

2.7 CHARACTERISATION OF NETWORK POWER OUTAGE

The nature of power outage in an integrated hierarchical network site can be categorized based on the outage causative factor and the degree of the outage impact on network robustness at the site. These are briefly discussed.

2.7.1 Nature of Free and Forced Outage at a Network Site

Power outage at a network site can be categorized as free outages and forced outage based on the inductive and causative factors. Free outages are spontaneous outage which occurs when subcomponent operational states are outside critical limits. Free outages also include all equipment random shutdowns that result from functional module lifetime expiry. Forced outages are scheduled predefined outages that include all configured system idle time and scheduled planned and unplanned maintenance shutdowns.

2.7.2 Nature of Partial and Total Power Outage at a Network Site

Power outage at a network site can also be categorized into partial outage and total outage based on the impact on the network robustness.

Partial power outages are outages that result from AC Subsystem failure that does not result in complete network impairment at an integrated hierarchical network site. Partial power outage occurs when failure emerge in a fractional part of the entire power system at a site such that it does not result in a total outage of power for the entire base station equipment. Partial power outages include a tolerable degree of failure of some AC supply unit such as a generator failure or public power outage or a worst scenario of complete AC supply outage, in which the some of the hierarchical transmission loads are still sustained transiently by the DC battery bank power. Partial outage could undermine the performance of the power system and reduce the reliability index to critical level that results in some percentage network outage on some transmission load at an integrated hierarchical site. Therefore the occurrence of worst case partial power failures on an access sites could result in connectivity loss on some low priority host sites. A great percentage of network reception and transmission outage on end sites are due to critical power episodes at access hub or intermediate sites.

On the other hand, the total power outage emerges when catastrophic failures that cause outright outage of power occurs at an integrated hierarchical network site and result in complete traffic loss at the site. This episode could also result when delay to restore power system operational efficiency above critical value occur during worst case partial outage. Complete power outage at an integrated site completely undermines network transmission at the site and impact substantial transmission capacity drop on the network. Total outage results from complete transmission load disconnection from the battery bank at critical low battery voltage at any network site. Total power outage events are consequences of fast draining rate of battery or failure of battery charging system during critical power episode or failure of the restoration of the complete AC unit or rectifier system before battery bank critical voltage state.

2.8 THE CRITICAL POWER RELIABILITY EPISODE

The critical power reliability episode occurs when the there is a complete AC power outage or complete rectifier system failure such that the supply of power to network transmission load at an integrated hierarchical site is completely dependent on the battery bank. Under this circumstance, automatic low voltage load disconnections occur sequentially on hierarchical transmission load at an integrated network site resulting in increasing traffic loss until complete network downtime occur at the site when the faulty AC unit is not urgently restored within battery runtime event. The level of traffic drop increases and the percentage of customer impacted increases due to more loads disconnection with depreciating battery bank voltage during this critical power episode.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

The chapter presents the strategies adopted for the sourcing and collection of reliability data. The primary reliability data collected for the major power subsystems were briefly described. The evaluation techniques used for the computation of secondary reliability data were presented. These data are analyzed using central tendency measure by considering the average value of the reliability data collected. The activities that were done during the study include:

- Examination of the nature and reliability features of the power subsystems on the network power system model.
- Assessment of the operational conditions for the functionality of each power subsystem
- Determination and characterisation of the nature of failure on the power system model under study.
- Collection and appraisal of the reliability data for the major power subsystems on the power model of the GSM network under study.
- Assessment of the redundancy topology of each subcomponent on the power model and the evaluation of the reliability standards of each major subcomponent using the collected reliability parameters.
- Assessment of the evaluated reliability standards to justify the effectiveness of the redundancy model of each of the power subsystem and also deduce possible factors that could flaw or enhance the redundancy model performance.

3.2 DATA COLLECTION TECHNIQUE

Reliability data were generally sourced through the study of equipment nameplates, system operational manuals and consultation with the network field engineers.

Manufacturers' specified Operational Data including subcomponents' Electric, Thermometric and Environmental operational limits, presented in Appendix1, were collected systematically and sourced from equipment nameplates and accessible operational manuals of installed power equipment. Primary reliability data such as Manufacturers' defined Mean Time To Failure (MTTF) for non-repairable subsystems, and the Mean time between Failure (MTBF) for repairable subsystems were collected randomly for power subsystems installed at various locations of the GSM network stations on the North West section of Airtel GSM Telecommunication Network.

Meanwhile, the Operator configured operating values, which are within Manufacturers' defined operational bounds, for normal working conditions and operator specified critical cut-off conditions for each power subcomponent at different hierarchical stations were obtained from System controls inbuilt data logs for memory systems. The collection and estimation of such parameters for memory-less power equipment with absence of inbuilt data logs were done through consultations with Airtel System Control Engineers. Most System uptimes (such as for generator, AVR, and rectifier) and downtime data were collected and sourced from subcomponents' event register memory through controlled observation. A few system uptimes (such as for battery) were collected through uncontrolled analytical study. Predefined reliability data specified and recommended by the Firm's Power Reliability Design Team were adopted to compensate for unavailable Manufacturers' defined reliability data.

All data corresponding to load specifications, operational specifications and raw reliability specifications collected for each power subcomponent on the model were presented in Appendix1.

3.3 DESCRIPTION OF RELIABILITY DATA OF MAJOR POWER SUBCOMPONENTS

The reliability data collected for hierarchical integrated stations and evaluated for each major power subcomponent, which were discussed in section 2.3, are presented in tabulations and described in terms of their constituent components.

3.3.1 Generator Reliability Data

The reliability data for the generator collected for some of the specimen hierarchical sites are presented in Table 3.1 to 3.3.

Table 3.1: Reliability data for Generator at Integrated Switch Station

Index	**KDMSC01**	**KDMSC02**	**KADMSS01**	**KNMSC01**	**ABMSC01**
Availability index, A	0.50000	0.64000	0.36650	0.55000	0.53500
Unavailability index, U	0.50000	0.36000	0.63350	0.45000	0.46500
Failure rate, (10 hr^{-1})	4.00	4.00	4.00	4.00	4.00
Repair rate,μ (hr^{-1})	0.50	0.50	0.50	0.50	0.50
MTBF (hr)	250	250	250	250	250
MTTR (hr)	2	2	2	2	2

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the North West Region, Airtel Nigeria Limited, February, 2009.

Table 3.2: Reliability data for Generator at Integrated Hub Station

Index	**KATBSC012**	**ZARBSC14**	**KEBBSC15**	**ZMBSC018**	**SOKBSC010**
Availability index, A	0.60000	0.45000	0.65000	0.54000	_
Unavailability index, U	0.40000	0.55000	0.35000	0.46000	_
Failure rate, (10 hr^{-1})	4.00	4.00	4.00	4.00	4.00
Repair rate,μ (hr^{-1})	0.25	0.25	0.25	0.25	0.25
MTBF(hr)	250	250	250	250	250

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.3: Reliability data for Generator at Terminal BTS Station

Index	**KD0030**	**KD0037**	**KD0041**	**KD0049**	**KD0050**
Availability index, A	0.6400	0.6500	0.4650	0.5500	0.5200
Unavailability index, U	0.3600	0.3500	0.5350	0.4500	0.4800
Failure rate, (10 hr^{-1})	4.00	4.00	4.00	4.00	4.00
Repair rate,μ (hr^{-1})	0.25	0.25	0.25	0.25	0.25
MTBF(hr)	250	250	250	250	250

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Generator Availability Indices

The availability index of a generator unit on the two-generator standby system is the ratio of the generator uptime to the sum total of generator uptime and downtime. The sum total of uptime and downtime is a year, which is the period of observation of the outage carried out during the study. Each generator unit is configured to have a steady absolute availability index of 0.500 but the actual availability index of a generator unit on the system could be within the neighborhood of 0.500 due to failure event of a unit or backup capability of a standby unit.

The actual availability indices evaluated for generator units at hierarchical station is signified by letter A in Table 3.1 to Table 3.3.

The generator downtimes include configured forced outages for a robust two-generator standby system with no free failure, scheduled maintenance shutdown outages, and free outages due to system shutdown to operational conditions beyond configured threshold limits. Therefore, the actual availability index of a generator unit on the system is dependent on the generator configured idle time, the Mean Time to Repair, the degree of sensitivity of the generator system to operational condition changes beyond critical limits, and the proximity of ambient condition ranges to configured operational bounds. The configured availability standard depends on the maintainability and the scale of redundancy of the generator system.

Generator Failure Rate

The generator failure rate is defined as the number of potential failure per unit time. It is symbolized by and measured in per thousand-hour. The generator failure rates collected for hierarchical stations were recorded in Table 3.1 to Table 3.3. Generator failure rate is dependent on the degree of system parameter changes (such as temperature, oil level or fuel level) and the degree of sensitivity of the generator system to operational states outside critical limits.

Generator Repair Rate

The generator mean time to repair is the average time to restore a faulted generator to operational efficiency, and the repair rate is the reciprocal value of the mean time to repair. The generator repair rate is denoted by and expressed in per hour. Most of the generator system on the network is sensored and enhanced to have high maintainability. The operational states of each generator unit on the system are monitored and regulated to allow the generator system tolerate faults when the operational state is beyond critical limit. Therefore, the Mean Time to Repair of a generator unit is dependent but not limited to the degree of automation of the generator to sense operational state on its Event register memory.

3.3.2 AVR Reliability Data

The reliability data for the Automatic Voltage Regulator collected for some of the hierarchical sites where the study was conducted are presented in Table 3.4 to 3.6.

Table 3.4: Reliability data for the AVR at Integrated Switch Station

Index	**KDMSC01**	**KDMSC02**	**KADMSS01**	**KNMSC01**	**ABMSC01**
Availability index A	0.99670	0.98333	0.97250	0.98200	0.99750
Unavailability index, U	0.00330	0.01667	0.02750	0.01800	0.002500
Failure rate, (10 hr^{-1})	0.00333	0.00333	0.00333	0.00333	0.00333
Repair rate,μ (hr^{-1})	0.333333	0.333333	0.333333	0.333333	0.333333
MTTF(hr)	30000	30000	30000	30000	30000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.5: Reliability data for the AVR at Integrated Hub Station

Index	**KATBSC012**	**ZARBSC14**	**KEBBSC15**	**ZMBSC018**	**SOKBSC010**
Availability index A	0.9500	0.9770	0.9850	0.9760	0.9820
Unavailability index, U	0.0500	0.0230	0.0150	0.0240	0.0180
Failure rate, (10 hr^{-1})	0.00333	0.00333	0.00333	0.00333	0.00333
Repair rate,μ (hr^{-1})	0.333333	0.333333	0.333333	0.333333	0.333333
MTTF(hr)	30000	30000	30000	30000	30000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.6: Reliability data for AVR at Terminal BTS Station

Index	**KD0030**	**KD0037**	**KD0041**
Availability index A	0.9990	0.9980	0.9985
Unavailability index, U	0.0010	0.0020	0.0015
Failure rate, (10 hr^{-1})	0.00333	0.00333	0.00333
Repair rate,μ (hr^{-1})	0.333333	0.333333	0.333333
MTTF(hr)	30000	30000	30000
MTTR(hr)	3	3	3

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

AVR Availability indices

AVR availability index is the ratio of the AVR uptime to the sum total uptime and downtime. It is denoted by letter A in Table 3.4 to Table 3.6. The AVR is designed to have a mission availability in which the system automatically energize in the event of public power availability and regulate the input power parameter (voltage, phase, frequency) within the load safety standards. The sum total uptime and downtime adopted for the AVR during the research is the total duration of public power supplied which was recorded from onsite power meters. Therefore the availability of the AVR is dependent on the performance of its output power parameter. The availability and performance of the AVR depend on the degree of sensitivity of the voltage, phasor, frequency monitoring and regulating module of the equipment.

AVR Failure Rate

The AVR failure rate is the number of failure event on the AVR subsystem per unit time. The reported AVR failure rate is evaluated as the reciprocal of the MTTF specified by the Firm Design Team. Therefore the AVR failure rate is dependent on the lifetime specifications of the voltage, phasor and frequency regulator modules.

3.3.3 Rectifier System Reliability Data

The reliability data for the Rectifier system collected for some of the hierarchical sites, where the study was carried out, are presented in Table 3.7 to 3.9.

Table 3.7: Reliability data for Rectifier at Integrated Switch Station

Index	**KDMSC01**	**KDMSC02**	**KADMSS01**	**KNMSC01**	**ABMSC01**
Availability index A	0.8960	0.8995	0.8975	0.8980	1.000000
Unavailability index, U	0.1040	0.1005	0.1025	0.1020	0.000000
Failure rate, (10 hr^{-1})	0.04	0.04	0.04	0.04	0.04
MTTF(hr)	25000	25000	25000	25000	25000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.8: Reliability data for Rectifier at Integrated Hub Station

Index	**KATBSC012**	**ZARBSC14**	**KEBBSC15**	**ZMBSC018**	**SOKBSC010**
Availability index, A	0.8890	0.8940	0.8950	0.8920	0.8970
Unavailability index, U	0.1110	0.1060	0.1050	0.1080	0.1030
Failure rate, (10 hr^{-1})	0.04	0.04	0.04	0.04	0.04
MTTF(hr)	25000	25000	25000	25000	25000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.9: Reliability data for Rectifier at Terminal BTS Station

Index	**KD0030**	**KD0037**	**KD0041**	**KD0049**	**KD0050**
Availability index A	0.8650	0.8720	0.8660	0.8710	0.8680

Unavailability index, U	0.1350	0.1280	0.1340	0.1290	0.1320
Failure rate, (10 hr^{-1})	0.04	0.04	0.04	0.04	0.04
MTTF(hr)	25000	25000	25000	25000	25000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Rectifier System Availability indices

The availability index of the rectifier system is the ratio of the system uptime to the sum total uptime and downtime. The rectifier downtimes are mainly due to free outages resulting from the failure of rectifier modules beyond the number required for the operation of the rectifier system, which are worst scenarios that results in critical power episode. The availability index of the rectifier system is dependent on the mean time to failure MTTF of the rectifier modules.

Rectifier System failure Rate

This is the number of failure per unit time on the rectifier system. It is expressed as the reciprocal of the mean time to failure.

3.3.4 Battery Reliability Data

The reliability data for the battery bank collected for some of the hierarchical sites, where the study was conducted, are presented in Table 3.10 to Table 3.12.

Table 3.10: Reliability data for Battery at Integrated Switch Station

Index	**KDMSC01**	**KDMSC02**	**KADMSS01**	**KNMSC01**	**ABMSC01**
Availability index A	0.9687500	0.9458333	0.9569444	0.9590277	_
Unavailability index, U	0.0312500	0.0541667	0.0430556	0.0409723	_
Failure rate, (10 hr^{-1})	1.0	1.0	1.0	1.0	1.0
MTTF(hr)	1000	1000	1000	1000	1000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.11: Reliability data for Battery at Integrated Hub Station

Index	**KATBSC012**	**ZARBSC14**	**KEBBSC15**	**ZMBSC018**	**SOKBSC010**
Availability index A	0.9750000	0.9708333	0.9583333	0.9541667	0.9250000
Unavailability index,U	0.0250000	0.0291667	0.0416667	0.0458333	0.0750000
Failure rate, (10 hr^{-1})	1.0	1.0	1.0	1.0	1.0
MTTF(hr)	1000	1000	1000	1000	1000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Table 3.12: Reliability data for Battery at Terminal BTS Station

Index	**KD0030**	**KD0037**	**KD0041**	**KD0049**	**KD0050**
Availability index A	0.9990	0.9980	0.9980	0.9982	0.9985
Unavailability index,U	0.0010	0.0020	0.0020	0.0018	0.0015
Failure rate, (10 hr^{-1})	1.0	1.0	1.0	1.0	1.0
MTTF(hr)	1000	1000	1000	1000	1000

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Battery Bank Availability Index

Battery bank Availability index was evaluated from the Battery Maximum Runtime Analysis conducted during Critical power event scenarios that result in total outage at the site. The Battery relative Availability index is evaluated as the ratio of the actual battery runtime to the rated battery bank runtime during critical reliability episode. The battery failure rate was evaluated from the Firm- defined MTTF ratings.

Battery bank Failure Rate

The battery bank failure rate is a function of a unit battery lifetime specification or Mean Time to Failure (MTTF), the redundancy topology of the battery bank and the stability of the ambient temperature and environmental conditions of the battery array. The failure rate of a unit battery is a reciprocal of its MTTF specification. Therefore the battery bank failure rate would be low for an array of identical batteries with a high lifetime specification for a unit. The battery bank failure rate would also be low for greater number of standby strings in the combinatorial battery system. The stability of ambient temperature and environmental conditions within optimal battery operational ranges maximizes the actual lifetime of a unit battery and thus guarantee high Mean Time to Failure for the entire battery system.

3.4 DATA EVALUATION TECHNIQUE

Primary data collected from operational manuals, equipment nameplates, system event register and those recommended during consultations with the Firm's design team were further used in the computation of secondary reliability data. These include the availability indices for each power subsystem at hierarchical GSM stations, the Mean Time Between Failure (MTBF) for repairable subcomponent on the model, such as the generator, which will be used in the computation of its failure rate, β.The Failure Rates of non-repairable power subcomponents on the model will be used to evaluate the Mean Time To Failure (MTTF) . The computation of the repair rate, μ, for repairable subcomponent will be used to evaluate the Mean Time to Repair (MTTR).These indices are computed as follows:

Availability, $= \mathrm{uptime}/(\mathrm{uptime} + \mathrm{downtime})$ (3.1)

Unavailability, $= 1 - \mathrm{A}$ (3.2)

$$= 1/\mathrm{MTBF} \quad (3.3)$$

$$= 1/\mathrm{MTTF} \quad (3.4)$$

$$= 1/\mathrm{MTTR} \quad (3.5)$$

U is the unavailability, is the failure rate for repairable subcomponent, is the failure rate for nonrepairable subcomponent and μ is the repair rate for repairable subcomponent.

3.5 DATA ANALYSIS

The data sets collected for each of the power subcomponent for a set of network sites were analyzed with MATLAB using the measure of central tendency tools. This means the average value of the data collected was used. In this case, the mean value of the sets of reliability data collected for each of the power subcomponent was evaluated. The mean value evaluated includes the mean availability index, , the mean failure rate, , of each power subcomponent for each hierarchical site, and the mean repair rate, , for all repairable subcomponents. The mean availability index of each subcomponent for each hierarchical site was compared with the absolute availability index for analysis. The reliability indices of each subcomponent in the power model were evaluated by applying the iterative approximation computational technique with the use of MATLAB version 7.4. Iterative approximation computational technique is a stepwise computational method in which the value of a function at a point can be approximated by progressively finding its value with incremental steps.

The reliability equations of the major power subcomponents were written in MATLAB scripts with the mean failure rates, and the number of redundancies as variables. These scripts were presented in Appendix 2.

3.5.1 Analysis of the Generator Reliability Data

The mean availability index, , of the generator set for each hierarchical sites was computed and presented in Table 3.13 so as to compare them relatively with the absolute availability index, , to make valuable deductions.

Table 3.13: Mean Values of the Reliability Data for the Generator Subsystem

Integrated site	**Absolute Standard Availability index**	**Mean Availability index**	**Deviation** $| \quad - \quad |$	**Mean Unavailability index**	**Mean failure rate** (10 hr^{-1})
Integrated switch site	0.5000	0.5183	0.0183	0.4817	4.00
Integrated hub site	0.5000	0.5600	0.0600	0.4400	4.00
Terminal end site	0.5000	0.5650	0.0650	0.4350	4.00

The absolute availability index, , on the two-generator standby redundancy system with one standby redundancy is the ideal availability index of a unit generator in such a system operating in an ideal environment within its standard schedule with no susceptibility to free outage. The nominal value of the absolute availability index of a unit generator on the two-generator redundancy system is 0.5000 for all hierarchical sites as shown in Table 3.13. This figure implies a 50% standard duty cycle for each generator in the two-generator system with no free failure that stimulate premature shutdown of an on-duty generator or activate sudden backup. The dominance of a mean availability index of 0.5183 by the generators in the integrated switch sites implies a prevalence of 51.83% duty cycle among the switch sites generator and a deviation of 1.83% from the percentage absolute value. This is an indication of some degree of free outages on the two-generator system in the integrated switch sites. The dominance of a mean availability index of 0.5600 by the generators in the integrated hub sites implies a prevalence of 56.00% duty cycle among the hub sites generator and a deviation of 6.00% from the percentage absolute value. This is an indication of more free outages on the two-generator system in the integrated hub sites. The dominance of a mean availability index of 0.5650 by the generators in the terminal end sites implies a prevalence of 56.50% duty cycle among the end sites generator and a deviation of 6.50% from the percentage absolute value. This is an indication of the prevalence of the highest free outages on the two-generator systems in the terminal end sites.

3.5.2 Analysis of the AVR Reliability Data

The mean availability index, , of the AVR systems for each hierarchical site was computed and presented in Table 3.14 so as to compare them relatively with the absolute availability index, , to make deductions.

Table 3.14: Mean Values of the Reliability Data for the AVR Subsystem

Hierarchical site	**Absolute Standard Availability index**	**Mean Availability index**	**Deviation** $|\quad - \quad|$	**Mean Unavailability index**	**Mean failure rate** $(10\ \text{hr}^{-1})$
Integrated switch site	1.00000	0.986406	0.013594	0.013594	0.00333
Integrated hub site	1.00000	0.974000	0.026	0.026000	0.00333
Terminal end site	1.00000	0.998500	0.0015	0.001500	0.00333

The absolute availability index, , of the AVR subsystem is 1.00000 and this figure implies 100% availability with zero percent unavailability, and this denotes high reliability of the AVR subsystem. The dominance of a mean availability index of 0.99850 by the AVR systems in the terminal end sites implies a prevalence of 99.85% availability with the lowest unavailability of 0.15% among the AVR systems in the end sites. This is an indication of the highest performance by the AVR systems at these terminal end sites. The dominance of the highest unavailability index of 0.02600, which is equivalents to 2.60%,by the AVR systems in the integrated hub sites, is an indication of the highest frequency of outages of AVR systems in the hub sites. The dominance of an availability index of 0.986406 or (98.64%) by the AVR systems in the integrated switch sites with a 0.013594 or 1.3594% difference from the absolute value is an indication of moderate performance by the AVR systems in the integrated switch sites.

3.5.3 Analysis of the Rectifier Reliability Data

The mean availability index, , of the rectifier system for each hierarchical site was computed and presented in Table 3.15 so as to compare them relatively with the absolute availability index, , to make deductions.

Table 3.15: Mean Values of the Reliability Data for the Rectifier Subsystems

Hierarchical site	**Absolute Standard Availability index**	**Mean Availability index**	**Mean Unavailability index**	**Mean failure rate** (10 hr^{-1})
Integrated switch site	1.00000	0.9182	0.0818	0.04
Integrated hub site	1.00000	0.8934	0.1066	0.04
Terminal end site	1.00000	0.8684	0.1316	0.04

The absolute availability index of the rectifier system is 1.00000 and this implies 100% availability with zero percent unavailability. This figure is an indicator of high reliability on the partial active redundancy rectifier system. The dominance of a mean availability index of 0.9182 by the rectifier systems in the integrated switch sites implies a prevalence of 91.82% availability with the lowest unavailability of 8.18% among the rectifier systems in the network. This figure is an indicator of the predominance of the lowest frequency of outages of rectifier systems in the integrated switch sites. The dominance of the highest unavailability index of 0.1316 equivalent to 13.16%, by the rectifier systems in the end sites, is an indication of the prevalence of the lowest performance of rectifier systems in the end site on the network. The prevalence of a mean failure rate of $0.04/10^3$hr among all the rectifier systems in all hierarchical sites is an indication that the modules in all the sites are identical.

3.5.4 Analysis of the Battery Bank Reliability Data

The mean availability index, , of the battery bank for each hierarchical site was computed and presented in Table 3.16 so as to compare them relatively with the absolute availability index, , to make deductions.

Table 3.16: Mean Values of the Reliability Data for the Battery bank

Hierarchical site	Absolute Standard Availability index	Mean Availability index	Mean Unavailability index	Mean failure rate (10 hr^{-1})
Integrated switch site	1.000000	0.95763885	0.04236115	1.0
Integrated hub site	1.00000	0.95666666	0.04333334	1.0
Terminal end site	1.00000	0.9983400	0.00166	1.0

The absolute availability index, , of the battery bank system is 1.00000 and this figure implies 100% availability with zero percent unavailability, and denotes high reliability.

The dominance of an availability index of 0.99834 by the battery bank system in the terminal end site implies a 99.83% availability of battery bank with a difference of 0.00166 from the absolute value. This differential equals the unavailability index of the battery bank on the end sites of the network. The exhibition of the lowest unavailability index by the end sites battery bank among all other hierarchical sites in Table 3.16 is an indication of the highest performance of battery bank in the end site.

The reliability of the power Holding Company of Nigeria (PHCN) equipment such as transformers and other accessories are not considered in this study due to unavailability of the data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The reliability results evaluated based on the redundancy model of each of the major power subcomponents were presented in tabular formats. Assessments of the reliability standards of each major power subsystem for the impacts of practices and considerations that causes variations of parameters under certain constant conditions were discussed. The impacts of critical episode events on network outage and customers were also discussed.

4.2 ASSESSMENT OF POWER SUBCOMPONENT RELIABILITY STANDARD

The reliability standard of each of the subcomponent was assessed based on their redundancy model under ideal environmental conditions, and the outcomes were attributed to certain dominant factors in the GSM technical environment.

4.2.1 Assessment of the Generator Reliability Standard

The results of the reliability of the generator system which were evaluated based on the n-identical generator standby redundancy system was assessed by varying the number of unit generator in the system at constant failure rate and presented in Table 4.1.

Table 4.1: The Impact of the Variation of Number of Redundancies in a Generator Standby

In Table 4.1, it could be deduced that an increase in the number of units on the system would increase the number of redundancies in the system and thus result in the maximization in the reliability index of the system in accordance to the diminishing trend of the added weight, w_{gen} with increasing number of unit generator down Table 4.1. In contrast, the configured standard absolute availability index of a unit generator on the system would be expected to diminish with increase in the number of redundancies. This is because increase in number of generator will reduce the number of time a particular generator will be working. For instance if the number of

No. of Generator unit N	**Failure rate** (10 hr^{-1})	**Optimal operating Temp** (^{o}C)	**Reliability index of Generator set R**	**Weight of the series for the last nth term**
2	4.00	70	0.9999	0.004
3	4.00	70	0.9999	0.000008
4	4.00	70	0.9999	0.000001067
5	4.00	70	0.9999	1.066666667 ε-11
6	4.00	70	1.0000	8.533333335 ε-15

generators is two, each generator will be programme to work for a period of twelve hours each. However if the number of generators in the redundancy system is four, each generator can only work for a maximum of six hours. The weight w_{gen} is the incremental value contributed to the reliability power series by the last nth term of the reliability equations presented in chapter two. As the number of unit, n, tends to infinity, the value of the series-sum grows while the incremental value contributed by the last nth term diminishes. Therefore, the trend of the weight with increasing nth term gives the inherent behavior of the series-sum as n sequentially tends to infinity.

The trend of the reliability result of the generator standby system is an evidence of reasons why long-term downtime of a unit generator failure is not much tolerated on the two-generator system as delay in optimum restoration would drastically strain the reliability of the generator redundancy system.

4.2.2 Assessment of the Rectifier System Reliability Standards

Organization technical culture and maintenance practice impacts the real time network power system reliability and the number of active redundancies on the rectifier system. The scheduled nature of planned maintenance for efficient allocation of repair resource could result in delay in the restoration and replacement of faulty rectifier modules on a rectifier system at a hierarchical network station and thus vary the number of real time active redundancies on the rectifier system at the network station. The impact of such practice on the reliability standard of the rectifier system at a network station was assessed by varying the number of active module for the partial redundancy rectifier system at constant failure rate and optimal operating condition in accordance to equation [2.3], and the result was shown in Table 4.2.

Table 4.2: Impact of Variation in the Number of Active Module on the Rectifier System Reliability Standards.

No. of active rectifier module N	**Failure rate β_{rec} (10^{-3}hr^{-1})**	**least number of active module**	**Optimal operating Temp** (^{o}C)	**Reliability index of Rectifier R_{rec}**
6	0.04	4	20	1.0000
8	0.04	4	20	1.0000
10	0.04	4	20	1.0000
12	0.04	4	20	1.0000
14	0.04	4	20	1.0000

In Table 4.2, it can be deduced that as the number of functional modules in the rectifier partial active redundancy system increases, the reliability index of the system gradually increases and peak at unity for some varying number of active module redundancies, then depreciates as the number of active modules increases to fourteen. Therefore the absolute standard availability index of the rectifier system would also increase with increase in the number of redundancies of the rectifier module. This justifies the installation of greater rectifier module redundancy at higher integrated hierarchical site at optimum efficiency. The trend of the reliability results in Table 4.2 is an indication that the partial redundancy system can tolerate redundancy reduction to some certain critical thresholds without much impact on the reliability value. Therefore the partial redundancy system can tolerate some degree of delay before restoration to optimum efficiency in the event of some unit failures.

The GSM power rectifier system at hierarchical stations consists of specific lifetime non-repairable identical rectifier modules. The rectifier system reliability and availability is dependent on the lifecycle specification of a unit module. The life cycle specification of a unit module is a function of its failure rate. Installation of various brands of rectifier system with differential lifetime specifications of module at different subsection of the network under study could impact difference in the actual failure rate of module at hierarchical network stations and thus affect the reliability and the availability index of this equipment at these stations .Rectifier system ageing and depreciations for different generation of network sites with the same rectifier brand could also impact variation in the real time failure rate of the module as well as the reliability standards at these sites. Therefore for a partial active redundancy system with n-identical rectifier modules, the impact of the lifetime specification was verified by varying the failure rate at constant number of redundancies and at constant optimal temperature and environmental conditions. The result of this assessment is shown in Table 4.3.

Table 4.3: Impact of Failure Rate Variation on the Rectifier System Reliability Index

No. of active rectifier module N	**Mean Time To Failure MTTF** (hr)	**Failure rate** β_{rec} (10^{-3}hr^{-1})	**Least number of active module**	**Optimal operating Temp** (°C)	**Reliability index of Rectifier** R_{rec}
12	20000	0.050	4	20	1.0000
12	25000	0.040	4	20	1.0000
12	30000	0.033	4	20	1.0000
12	35000	0.029	4	20	1.0000
12	40000	0.025	4	20	1.0000

It could be deduced from the result in Table 4.3 that an increase in the lifetime specification of a rectifier system would maximize the expected availability index of the system, but does not intrinsically imply a progressively increase in the nominal value of the reliability index as R_{rec} is not directly proportional to the lifetime specification. It is greatly high for failure rate values of β_{rec} =0.040/10^3hr and β_{rec} =0.025/10^3hr but generally approaches unity for all small values of failure rate.

Low failure rate status of rectifier module justifies the high availability indices exhibited by rectifier system in new generation sites on the network section under study. The exhibition of high reliability index for failure rate specification of 0.040/10^3hr is an evidence of the high reliability standard of most the rectifier systems at hierarchical sites on the network under study.

4.2.3 Assessment of the Battery Bank Reliability Standards

The m-series connected battery is a -48V combinatorial system. The choice of the value of the number of series battery per string, m, may depends on battery bank design trends, scalability and availability of unit battery, space and cost considerations. For most practical cases on the GSM power model, m=4 in which each battery unit has a rating of 12V or m=8 for which battery unit has a rating of 6V. Therefore, the scalability of the battery rating, is a major factor that affects the reliability of the series combinatorial system provided all installation conditions are intact.

The impact of the battery rating on the reliability index of the battery was assessed by varying the value of m for a constant number of strings, failure rate and at constant temperature and environmental conditions in accordance to equation (2.6). The result of this assessment was shown in Table 4.4.

Table 4.4: Impact of Battery scalability on Battery bank Reliability Standards

No. of series battery per string **M**	**No. of standby strings** **N**	**Failure rate** β (10^{-3}hr^{-1})	**Optimal operating Temp** (^{o}C)	**Reliability index of Battery system** R_{batt}
2	8	1.0	20	1.0000
4	8	1.0	20	1.0000
6	8	1.0	20	1.0000
8	8	1.0	20	1.0000
10	8	1.0	20	0.9960
12	8	1.0	20	1.0000
14	8	1.0	20	1.0000
16	8	1.0	20	1.0000

It could be deduced from Table 4.4 that the reliability index of a battery bank system is greatly high for m=16 in which 3V rating battery units are used on the battery system; for m=4 in which 12V rating battery units are used on the battery bank system; and for m=8 for which 6V rating battery units are used on the battery system at constant failure rate, temperature and environmental conditions. Therefore, the reliability result in Table 4.4 reveals the significance of scalability consideration on the battery bank redundancy design planning when all other parameters are kept constant.

In similar manner, the Firm design with variation in the number of battery string for hierarchical levels of network site provide a basis for the assessment of the impact of the variation in the number of standby strings on the reliability standard at hierarchical network stations. The impact of the variation in the number of standby strings on the reliability standard at hierarchical network stations was assessed with the assumption of a constant number of identical series batteries at constant temperature and environmental conditions. The result was presented in Table 4.5.

Table 4.5: Impact of the Number of Standby Strings on the Battery bank Reliability Standards

No. of series battery per string, M	**No. of standby strings N**	**Failure rate β (10^{-3}hr^{-1})**	**Optimal operating Temp (^{o}C)**	**Reliability index of Battery system R_{batt}**	**Weight of the series for the last n^{th} term**
4	2	1.0	20	1.0000	4.0 ∈-3
4	4	1.0	20	1.0000	1.066666667 ∈-8
4	6	1.0	20	1.0000	8.533333333 ∈-15
4	8	1.0	20	1.0000	3.250793651 ∈-21
4	10	1.0	20	1.0000	7.223985891 ∈-28

It could be deduced from Table 4.5 that as the number of standby strings increases with other conditions constant, the reliability standard of the battery bank approaches unity with depreciating value in the added weight. Therefore the reliability index as well as the availability index of a battery bank on the network power model tends to unity and would be maximized for increasing number of standby strings. This is a major practice in the design of hierarchical integrated station in which backbone integrated stations are configured with the greatest number of battery standby strings so as to ensure it possess the greatest sustenance time in the event of critical power episode**.**

4.3 CRITICAL EVENT ANALYSIS AT TYPICAL HIERARCHICAL STATION.

The performance data of battery at critical events episode before system restoration for different integrated hierarchal station was observed and recorded for the analysis of configured outage of low priority sites at integrated GSM network station and the assessment of the impct on customers.The data were collected for three categories of integrated GSM network station and the impact on station transmission load was presented in Table 4.6 to 4.8.

Table 4.6: Critical Power Event Impact at the KDMSC01 Integrated Switch Site

Interval (hr)	**Battery Energy ouput** (%)	**Load connected** (kW)	**No. of integrated hub site impacted**	**No. of integrated end site impacted**	**No. of customers impacted based on the network design**
4	94	250	_		_
8	82	250	_		_
12	74	230	_	1	7500
16	66	230	_	1	7,500
20	51	200	12	40	30,000
24	43	0	20	102	765,000

The data collected during a particular critical power event at integrated site, KADMSC01 , supporting GSM switch backbone site, Base Station Controller and a BTS end site, was presented in Table 4.6.

The battery output power dropped to 74% in the twelveth hour of critical power episode and power unit disconnected from the BTS loads resulting in complete outage of only the end site installed in the same location with the switch and blocking a total number of 7500 subscribers at peak busy hour .Some of the homing hub sites went down through cascaded link outage as the collocated BSC(KADBSC021) loads at the site were disconnected from the battery source after the 20th hour during critical power episode at the site,and a total number of 30000 subscribers would be impacted at peak call hour through six BTS end sites cascaded outage.The battery ouput power dropped to 43% after the 24th hour of the critical power event ,and the entire loads on the Battery bank were disconnected ,resulting in complete outage of the collocation station and an estimate of 765000 subscribers would be impacted during busy peak hour periods.

Table 4.7: Critical Power Event Impact at the KAD027 Integrated Hub site

Interval (hr)	**Battery Energy ouput (%)**	**Load connected** (kW)	**No. of integrated end site impacted**	**No. of customers impacted**
2	98	15	_	_
4	84	15	_	_
6	72	10	1	7,500
8	66	10	1	7,500
10	50	10	1	7,500
12	42	0	8	60,000

Table 4.8: Critical Power Event Impact at KD0040 End Site

Interval (hr)	**Battery Energy ouput** (%)	**Load connected** (kW)	**No. of customers impacted in terms of No. of traffic channels**
2	96	10	_
4	84	10	_
6	73	10	_
8	64	10	_
10	44	0	7,500

The impact of the critical power event scenario at end site KD016 is presented in Table 4.8 above. It could be observed that the entire BTS loads at the station remained connected to the battery power supply unit up to the 8th hour during the event of critical power episode. The battery output power dropped to 44% ten hours after the commencement of critical power episode, and a total end site outage occurred at the station, blocking out 7500 subscribers at busy peak time hour.

The battery bank reliability result with identical batteries of constant failure rate and constant number of m-series connected battery shows that the battery system reliability and availability maximizes with increasing number of redundancies in the standby topology and so do the sustenance time and the performance of the battery bank at hierarchical sites during critical power episode. The aggregate number of customers impacted per unit time during critical power episode at hierarchical sites, on the other hand, decreases with increasing value of reliability and availability indices.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter presents the limitations which were constraints during the course of the study. The summary of the findings discovered upon the assessments of the efficiency of the operating power model, the operational conditions, and the reliability results obtained are highlighted. The conclusions on the deductions made on the reliability study are also listed. Recommendations on practices to enhance reliability standards on a GSM power system are outlined.

5.2 LIMITATIONS

The limitations and constraints encountered during the data collection stage of the study include the following:

1. The unavailability of chronological data sources on the power system of the network under study to provide profound understanding of power subcomponents reliability behavior.
2. System complexity which resulted in slow mastery of subsystem functional structure and ordeal in the acquisition of data.
3. System diversity which resulted in the assumption of a representative for some reliability data. However system diversity provides data variations used for the assessment of the impact of parameter changes on the network reliability standards.
4. Inadequate access to Manufacturers' defined reliability data for some power equipment which resulted in the adoption of Operator recommended parameters.

5.3 SUMMARY

The efficiency of the network power system model depends on the degree of automation of the subcomponent, the level of sensitivity of failure conditions, the degree of ambient condition changes, critical limit markings, the redundancy mode of each subcomponent and the degree of redundancy in each subcomponent subsystem.

Automation of the subcomponent eases fault detection, improves equipment maintainability and shortens repair time. The level of sensitivity determines the number of failure parameters that could affect the equipment availability or performance on the model. High level of equipment sensitivity enhances the equipment long-term reliability reduces depreciation rate and maximize equipment optimum efficiency status.

The Ambient temperature bounds and other environmental condition limits, such as the relative humidity level, are often within normal working operational ranges. Therefore, the frequency of environmental-based free outage equipment shutdowns is minimal.

It was observed throughout the period of the study that the environmental conditions such as temperature and humidity for the operation of most of the outdoor power subsystems are relatively stable such that the network power system model is much invulnerable to environmental condition changes.

The reliability results are evidence of strategy on how realities in the technical environment of GSM power system operations are addressed. These results justify the strategy and scheme of maintenance routine adopted on the power system of the firm.

5.4 CONCLUSION

In the course of the study, it was ascertained that the reliability configuration standard on the GSM power system is dynamic because it can easily be varied to suit the desired reliability standard of the operator. It is driven by changes in organization economic or operational environments, ergonomics, geographic and climatic conditions. It was discovered that the reliability standards of the power subcomponents of the GSM networks studied are within reasonable robust level that is not compromised by cost considerations that might undermine reliability value and result in excessive critical outages events.

It could be concluded that in the assumption of optimal working conditions of all the subsystems and ideal maintenance practice by the firm, then, the reliability standards of the GSM power model would greatly depend on topological design factors such as the:

1. Redundancy mode of each subcomponent.
2. Degree of redundancy of each subcomponent.
3. Failure ratings or the lifecycle of the subcomponent units
4. Scalability of the subcomponent unit used on the system

5.5 RECOMMENDATIONS

1. GSM power system robustness could be strengthened by integrating alternative forms of power sources on the power system at a network site so as to minimize network vulnerability due to power outages.

2. For reliability and availability indices to be maximized there is the need for the integration of different redundancy mode (standby and active redundancies) on the GSM power system. For standby redundancy, only one equipment is working while others are not energise.When the equipment that is working fail, one of the standby equipment will pick up.However,in an active redundancy system, all the equipment are power up at the same time.
3. Reliability system should be on a redundancy scale that balances cost minimization and value maximization by practices which limit redundancies without excessively compromising reliability value. In other words, there should be a balance between the cost and reliability.
4. Enhanced automation of subcomponents on a GSM network power system is a useful practice to bolster the maintainability of the power subsystems, improve maintenance and enhance subsystems availability on the network power system.

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APPENDIX 1

ELECTRIC, THERMOMETRIC AND RELIABILITY DATA OF POWER SUBCOMPONENT AT HIERARCHICAL NETWORK STATION

1.1 INTEGRATED SWITCH STATION

Generator

s/n	Vendor	Gen KVA Rating	Output power rating (kW)	Voltage rating (V)	Current rating (A)	Rated temp (^{0}C)	Operating temp (^{0}C)	Critical temp (^{0}C)	Rated Service hour (hr)	Operation time (hr)	MTTR (hr)	MTTF (hr)	Total Load (kW)
1	Cumin	400	385	415	560	85	65	80	200	12	2	25,000	290
2	Cumin	400	385	415	560	90	68	80	200	12	2	25,000	288
3	Cumin	400	385	415	560	85	70	80	200	12	2	25,000	250
4	Cumin	400	385	415	560	85	64	80	200	12	2	25,000	218
5	Cumin	400	385	415	560	85	71	80	200	12	2	25,000	195
6	Cumin	400	385	415	560	90	64	80	200	12	2	25,000	250
7	Cumin	400	385	415	560	90	68	80	200	12	2	25,000	288
8	Cumin	400	385	415	560	90	70	80	200	12	2	25,000	300
9	Cumin	400	385	415	560	85	66	80	200	12	2	25,000	315
10	Cumin	400	385	415	560	90	68	80	200	12	2	25,000	299

Source: Statistical Survey and Evaluation of Power Subsystem Reliability Statistics on the NorthWest Region, Airtel Nigeria Limited, February, 2009.

Automatic Voltage Regulator

S/N	Input voltage ( )	Output voltage ( )	Tolerance ( )	Operating temp (^{0}C)	Critical temperature (^{0}C)	MTTF (hrs)	MTTR (hrs)
1	220-250	220-240	±0.5	27	40	30000	3
2	220-250	220-240	±0.5	27	40	30000	3
3	220-250	220-240	±0.5	27	40	30000	3
4	220-250	220-240	±0.5	27	40	30000	3
5	220-250	220-240	±0.5	27	40	30000	3
6	220-250	220-240	±0.5	27	40	30000	3
7	220-250	220-240	±0.5	27	40	30000	3
8	220-250	220-240	±0.5	27	40	30000	3
9	220-250	220-240	±0.5	27	40	30000	3

Source: Statistical Survey on the Power Subsystems on the North West Region of Airtel Nigeria Limited, 2009.

Rectifier

S/N	Max Input voltage ( )	Output voltage ( )	Operating Temp (^{0}C)	Critical Temp (^{0}C)	MTBF (hr)	MTTR (hr)
1	240	48	20	40	25000	3
2	240	48	22	40	25000	3
3	240	48	20	40	25000	3
4	240	48	19	40	25000	3
5	240	48	20	40	25000	3
6	240	48	21	40	25000	3
7	240	48	21	40	25000	3
8	240	48	22	40	25000	3
9	240	48	20	40	25000	3

Source: Statistical Survey on the Power Subsystems on the North West Region of Airtel Nigeria Limited, January, 2009.

1.2 INTEGRATED HUB SITE Generator

Vendor	Gen KVA Rating	Output power rating (kW)	Voltage rating (V)	Current rating (A)	Rated temp (^{0}C)	Operating temp (^{0}C)	Critical temp (^{0}C)	Rated Service hour (hr)	Operation time (hr)	MTTR (hr)	MTTF (hr)	Total Load (kW)

Perkins	27	21.6	415	39	80	62	70	250	12	2	25,000	12
Perkins	27	21.6	415	39	75	64	70	250	12	2	25000	15
Perkins	27	21.6	415	39	80	61	70	250	12	2	25,000	17
Perkins	27	21.6	415	39	80	64	70	250	12	2	25,000	12
Perkins	27	21.6	415	39	75	62	70	250	6	2	25,000	12
Perkins	27	21.6	415	39	80	63	70	250	6	2	25,000	15
Perkins	27	21.6	415	39	75	63	70	250	6	2	25,000	15
Perkins	27	21.6	415	39	75	64	70	250	6	2	25,000	14
Perkins	27	21.6	415	39	75	66	70	250	6	2	25,000	12
Perkins	27	21.6	415	39	75	64	70	250	6	2	25,000	14

1.3 TERMINAL END SITE

Generator

Vendor	**Gen KVA Rating**	**Output power rating (kW)**	**Voltage rating (V)**	**Current rating (A)**	**Rated temp (^{0}C)**	**Operating temp (^{0}C)**	**Critical temp (^{0}C)**	**Rated Service hour (hr)**	**Operational Time (hr)**	**MTT (hr)**
Lister	18.5	15	415	25	80	64	70	10	6	4
Lister	18.5	15	415	25	75	62	70	10	6	4
Lister	18.5	15	415	25	75	62	70	10	6	4
Lister	18.5	15	415	25	75	65	70	10	6	4
Lister	18.5	15	415	25	75	63	70	10	6	4
Lister	18.5	15	415	25	75	63	70	10	6	4
Lister	18.5	15	415	25	75	64	70	10	6	4
Lister	18.5	15	415	25	75	65	70	10	6	4

Lister	18.5	15	415	25	80	64	70	10	6	4
Lister	18.5	15	415	25	80	65	70	10	6	4

Source: Statistical Survey on the Power Subsystems on the North West Region of Airtel Nigeria Limited, January 2009.

1.4 Backbone site

s/n	Vendor	Gen KVA Rating	Output power rating (kW)	Voltage rating (V)	Current rating (A)	Rated temp (^{0}C)	Operating temp (^{0}C)	Critical temp (^{0}C)	Rated Service hour (hr)	Operation time (hr)	MT (hr)
1	Perkins	30	24	415	45	75	64	70	12	6	2
2	Perkins	30	24	415	45	80	64	70	12	6	2
3	Perkins	30	24	415	45	75	65	70	12	6	2
4	Perkins	30	24	415	45	75	62	70	12	6	2
5	Perkins	30	24	415	45	80	62	70	12	6	2
6	Perkins	30	24	415	45	80	64	70	12	6	2
7	Perkins	30	24	415	45	75	63	70	12	6	2
8	Perkins	30	24	415	45	75	64	70	12	6	2
9	Perkins	30	24	415	45	80	65	70	12	6	2
10	Perkins	30	24	415	45	80	63	70	12	6	2

Source: Statistical Survey on the Power Subsystem on the North West Region of Airtel Nigeria Limited, January, 2009.

1.5 Electric, Thermometric, and basic Reliability Data of Battery collected for hierarchal Stations

Site	**Brand**	**Rated voltage** (V)	**Rated Energy** (Ampere-Hour)	**Rated temp** (^{0}C)	**Operational temp** (^{0}C)	**Critical temp** (^{0}C)	**MTTF** (hr)	**Mean failure rate** ( ) ($10^{-3}hr^{-1}$)
backbone	Emerson	12	170	40	20	30	1000	1.0
Hub	Grintek	12	170	30	20	28	1000	1.0
End	Battery tech	12	165	30	20	28	1000	1.0

Source: Statistical Survey on the Power Subsystems on the North West Region of Airtel Nigeria Limited January, 2009

Appendix 2.3

MATRIX SCRIPT FOR THE COMPUTATION OF THE GENERATOR RELIABILITY INDEX

```
%Evaluation of the reliability index of Generator standby redundancy system using equation presented in sem\inar 1
betag=0.004;%failure rate of the generator unit in per hour.
t=1;%Observed time interval in hours.s
 n=4;%'n'equals the number of unit generator in the standby redundancy system.

sum1=0;
R=exp(-betag*t);%Compute the reliability index of a unit generator
   for i=(1:1:n-1);
      r(i)=(betag*t).^i/factorial(i);
      sum1=sum1+r(i);
   end
  r(i);sum1;
R_gg=R+R*sum1;%Compute the Reliability Index a n-identical generator standby redundancy system.
```

Appendix 2.2

MATRIX SCRIPT FOR THE COMPUTATION OF THE RECTIFIER SYSTEM RELIABILITY INDEX

```
%Evaluation of the Reliability Index of the Rectifier System using eqution presented in seminar 1
m=12;%The number of rectifier module for a Backbone Station


q=4;%the least number of rectifer module in the system.
beta2=0.00004;%the failure rate of a rectfier module.
t=1;%the observed time interval.
Q=exp(-beta2*t);
p=1-Q;
sump=Q^m;
for i=1:1:(m-q);
   Q_rec(i)=factorial(m)*p^i*Q^(m-i)/(factorial(i)*factorial(m-i));
   Q_rec(i)=Q_rec(i)+sump;%Compute the reliability index of the rectifier system.
end;
sump;m;Q_rec(i);
```

APPENDIX 2

MATLAB SCRIPTS FOR THE COMPUTATION OF SUBSYSTEM RELIABILITY INDICES

Appendix 2.1

MATRIX SCRIPT FOR THE COMPUTATION OF THE BATTERY BANK RELIABILITY INDEX

```
%Evaluation of Reliability index of a battery system using the  equation  presented in seminar 1

BETAb=0.001;%failure rate of battery unit in per hour.

t=1;%observed time interval in hours.

m=4;%m=the number of battery per string.

 n=8;%'n'equals the number of battery string at a backbone station.

 sum1=0;

R=exp(-m*BETAb*t);%Compute the reliability index of a single battery string.

   for i=(1:1:n-1);

      r(i)=(m*BETAb*t).^i/factorial(i);

      sum1=sum1+r(i);

   end

r(i);sum1;

  R_bscr=R+R*sum1;%Compute the Critical Reliability(battery system reliability) Index at a
  Backbone station.
```

Appendix 2.2

MATRIX SCRIPT FOR THE COMPUTATION OF THE RECTIFIER SYSTEM RELIABILITY INDEX

```
%Evaluation of the Reliability Index of the Rectifier System using eqution presented in seminar 1
m=12;%The number of rectifier module for a Backbone Station

q=4;%the least number of rectifer module in the system.
beta2=0.00004;%the failure rate of a rectfier module.
t=1;%the observed time interval.
Q=exp(-beta2*t);
p=1-Q;
sump=Q^m;
for i=1:1:(m-q);
   Q_rec(i)=factorial(m)*p^i*Q^(m-i)/(factorial(i)*factorial(m-i));
   Q_rec(i)=Q_rec(i)+sump;%Compute the reliability index of the rectifier system.
end;
sump;m;Q_rec(i);
```

Appendix 2.3

MATRIX SCRIPT FOR THE COMPUTATION OF THE GENERATOR RELIABILITY INDEX

```
%Evaluation of the reliability index of Generator standby redundancy system using equation presented in sem\inar 1

betag=0.004;%failure rate of the generator unit in per hour.

t=1;%Observed time interval in hours.s

 n=4;%'n'equals the number of unit generator in the standby redundancy system.



sum1=0;

R=exp(-betag*t);%Compute the reliability index of a unit generator

   for i=(1:1:n-1);

       r(i)=(betag*t).^i/factorial(i);

       sum1=sum1+r(i);

   end

  r(i);sum1;

R_gg=R+R*sum1;%Compute the Reliability Index a n-identical generator standby redundancy system.
```